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FHWA/IN/JHRP-92-23
Implementation Report

SUBGRADE RESILIENT MODULUS FOR PAVEMENT DESIGN AND PERFORMANCE

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by

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SUBGRADE RESILIENT MODULUS FOR PAVEMENT DESIGN AND PERFORMANCE

Implementation Report

The 1986 AASHTO Guide for the Design of Pavement Structures introduces the Resilient Modulus as a definite material parameter to characterize subgrade soil. The incorporation of resilient modulus into design practice requires development of testing capabilities and a procedure and data base to allow ready implementation. This study concentrated on development of a procedure to create the implementable resilient modulus for typical Indiana soils.

Five typical cohesive soils, ranging from an A-4 through A-6 to A-7(5) and A-7(6) classes were tested. It was found that laboratory compaction with impact procedures at standard Proctor energy at water contents near to optimum or slightly larger, depending on the soil, would create a soil fabric similar to that created in the field under current Indiana specifications. When this preparation is combined with the consideration created in this project for resilient modulus and the data from a "routine unconfined compression test", then the as-compacted modulus is obtainable somewhat readily for a specific location. This reduces the need for sophisticated dynamic testing equipment and its associated software.

In the field, in-service, the prepared subgrade experiences a variety of environmental conditions. Two seem especially important: freeze-thaw effects, and changes in water content. These have been included in the procedures developed in the project. The resilient modulus of the frozen - and thawed - soil states was developed through laboratory simulation. Additionally, a laboratory procedure was developed to add water, by injection, to the as-compacted soil. Relations were developed from results of testing to allow prediction of the change in modulus from the post-compaction change in water content, soil-by-soil.

From the foregoing results of this project, a procedure has been developed with which to determine the subgrade resilient modulus for use in pavement design. The procedure and associated charts and tables are presented below for new construction:

1) Identify the soil that will become the compacted subgrade. Procure a bulk sample for the laboratory (each specimen to be prepared requires about 3 pounds of soil).

2) Prepare an impact compacted specimen in the laboratory, 2.8 inches diameter and 5.6 inches height in a suitable mold, according to the criteria in Table 10.1 appropriate for the soil.

Table 10.1 Laboratory Compaction Criteria for Replication of Field Compacted Fabric

Site	Laboratory Compaction Method
South Bend (A-4/A-6)	Impact compaction at OMC to 1% wet of OMC with Standard Proctor energy
Fort Wayne (A-6)	Impact compaction at OMC with Standard Proctor energy
Washington (A-4)	Impact compaction at OMC with Standard Proctor energy
Bedford (A-7(6))	Impact compaction at 1% wet of OMC with Standard Proctor energy
Bloomington (A-7(5))	Impact compaction at 1.5-2% wet of OMC with Standard Proctor energy

3) Perform an unconfined compression test, using the specimen from (2), at a strain rate of 1 percent per minute. Calculate the stress, in psi, associated with 1 percent axial strain, $S_{u1.0\%}$.

4) Calculate the predicted <u>as-compacted</u> resilient modeling, in psi, from

$$M_R = -1599.66 + 833.83\ S_{u1.0\%} - 6.9683\ S_{u1.0\%}^2 \quad \text{(eqn. 4.8)}$$

5) Estimate the change in water content that is expected to occur in-service by using Table 10.2. The sampling that was performed in this project, and the work of Prapaharan, Altschaeffl, and Dempsey (1985) with its additional referenced works suggest strongly the equilibrium water content, in-service, will likely be near to that which represents 90% to 95% degree of saturation for Indiana conditions. One must know what was the original compaction specification requirement for the average water content of the as-compacted

Table 10.2 Resilient Modulus for Frozen Soils and Estimate of Water Contents after Construction

Sites	M_{RF} (psi)	As-compacted opt. w/c, %	Estimate of w/c at S_r = 90%	S_r = 95%
South Bend (A-4/A-6)	27000	9.8	10.8	11.4
Fort Wayne (A-6)	27000	16.8	17.2	18.2
Washington (A-4)	46000	15.0	16.4	17.4
Bedford (A-7(6))	27000	19.5	20.0	21.1
Bloomington (A-7(5))	27000	23.0	23.9	25.3

soil. Today, Indiana's earthwork specification aims for the average water content to be near to 1/2% dry of optimum water content. Thus, the change to be expected is the difference between the as-compacted average and the water content at the likely in-service degree of saturation.

6) Estimate the change in M_R that is expected from the change in water content predicted in (5) above. Presented below are the diagrams to allow this prediction, soil-by-soil.

7) Estimate M_R at equilibrium and call it the normal subgrade condition:

$$M_{RN} = M_{R\ as\text{-}comp} - \Delta M_R$$

Where ΔM_R is that due to the expected change in water content, from (6) above.

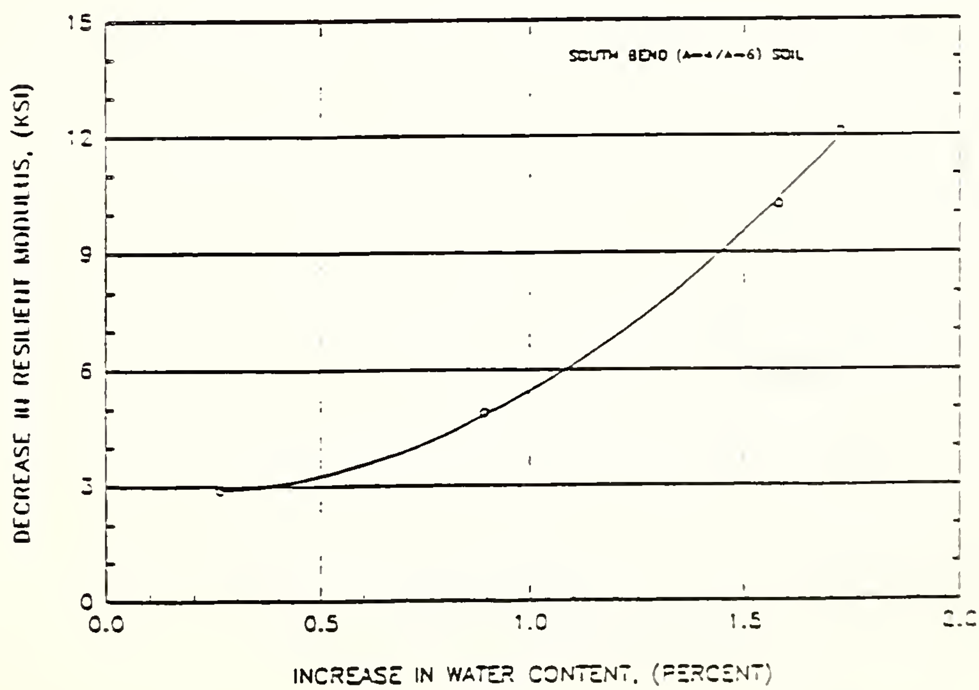

Fig. 10.1 Relationship Between ΔM_R and Δw - South Bend (A-4/A-6)

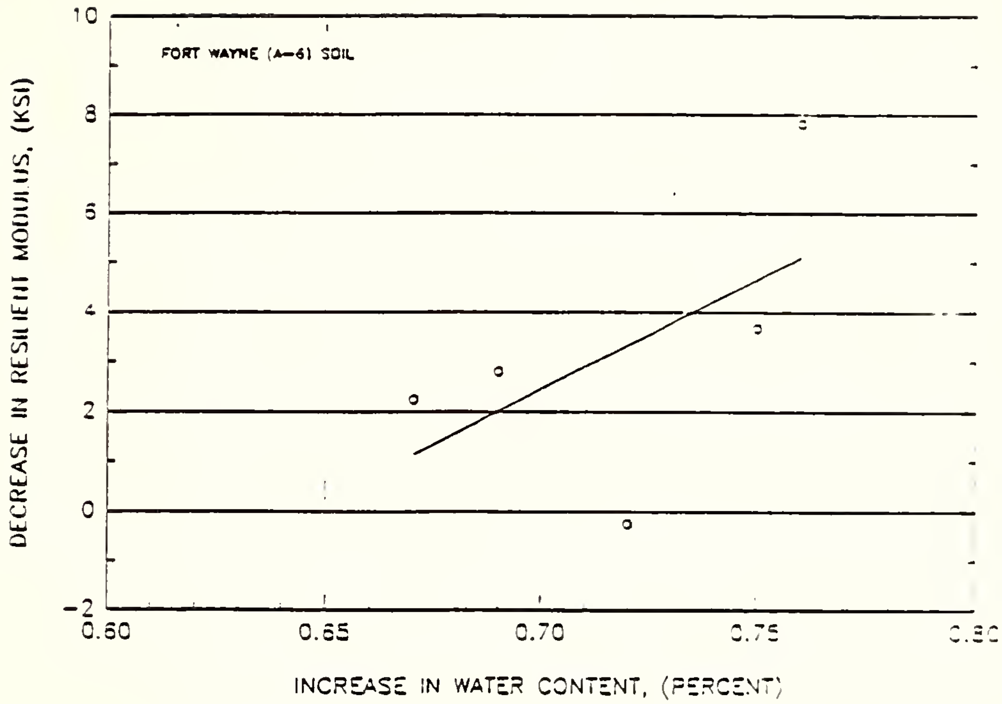

Fig. 10.2 Relationship Between ΔM_R and Δw - Fort Wayne (A-6)

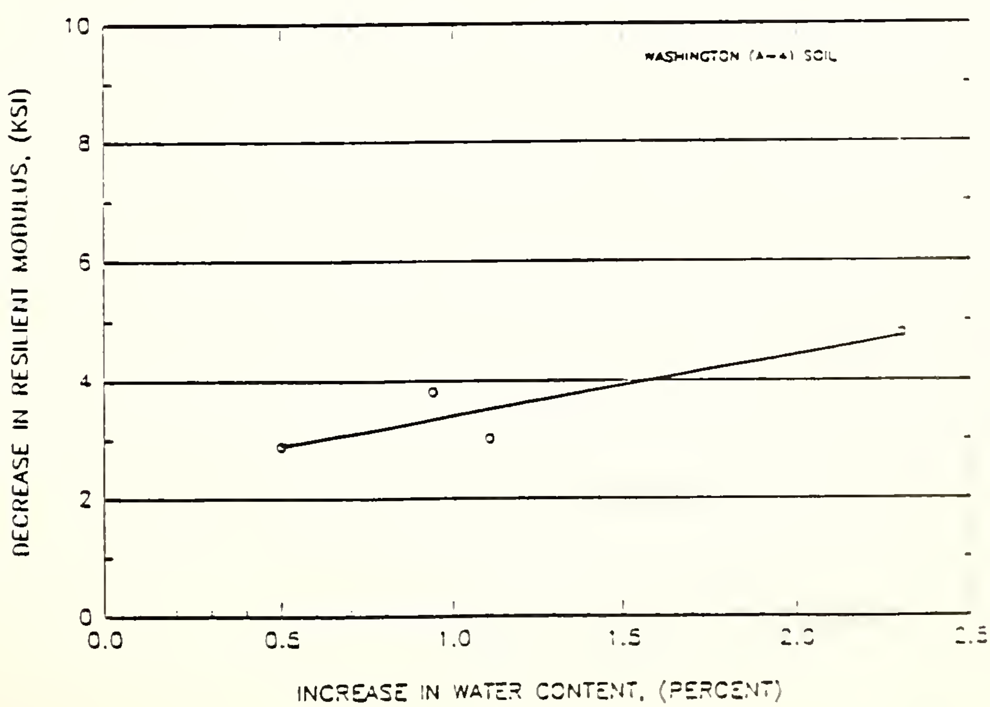

Fig. 10.3 Relationship Between ΔM_R and Δw - Washington (A-4)

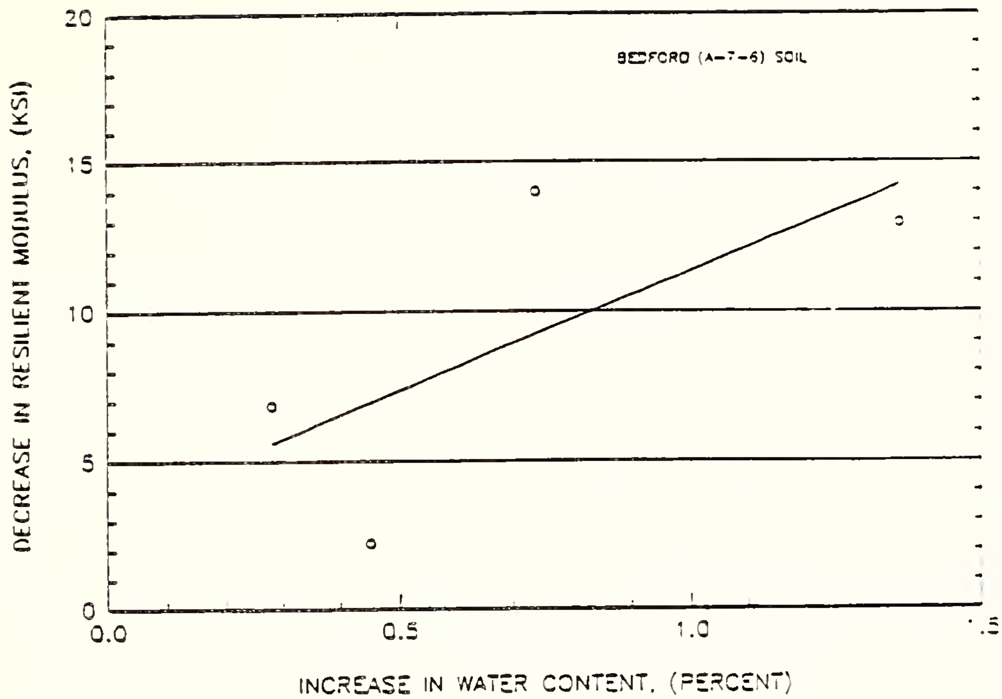

Fig. 10.4 Relationship Between ΔM_R and Δw - Bedford (a-7(6))

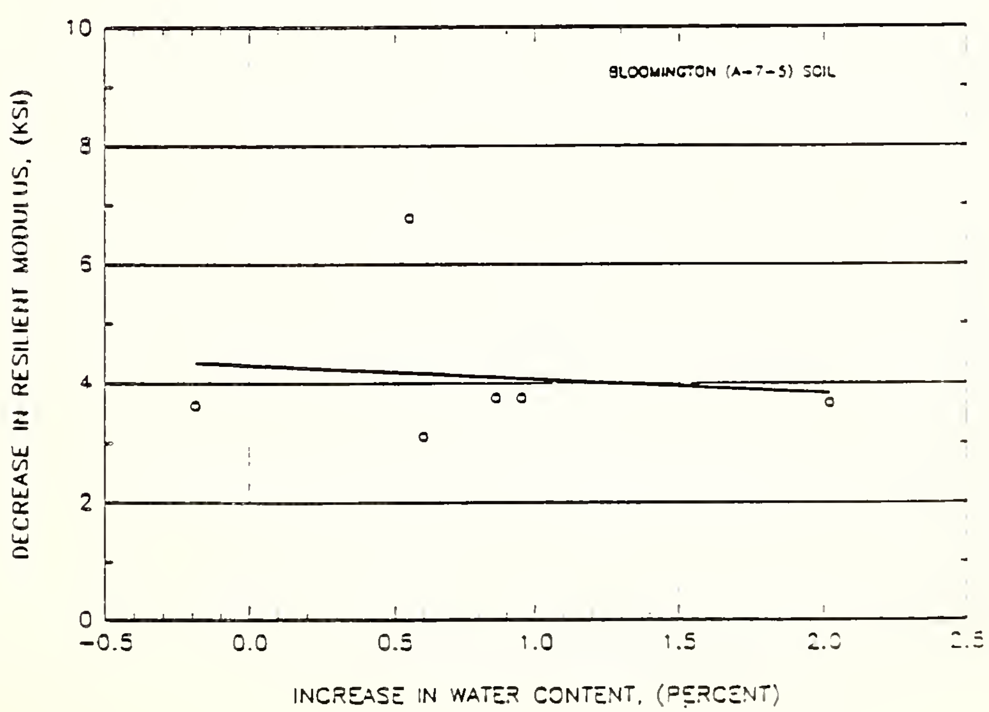

Fig. 10.5 Relationship Between ΔM_R and Δw - Bloomington (A-7(5))

8) Estimate M_R for the frozen condition by using Table 10.2 for the appropriate soil.

9) Estimate M_R for the thawed condition by using

$$M_{RT} = 2453.48 + 130.24 \, S_{u1.0\%} \qquad (5.3)$$

Where $S_{u1.0\%}$ is the stress causing 1.0% strain in the unconfined compression test for the normal condition. The magnitude of $S_{u1.0\%}$ is back calculated from eqn. 4.8 using M_{RN}, as above (item (7)).

10) Estimate M_R for each month by constructing a chart such as Fig. 10.12. This requires a judgment on when the subgrade will be frozen, when thaw is complete, and when the "normal" condition is present.

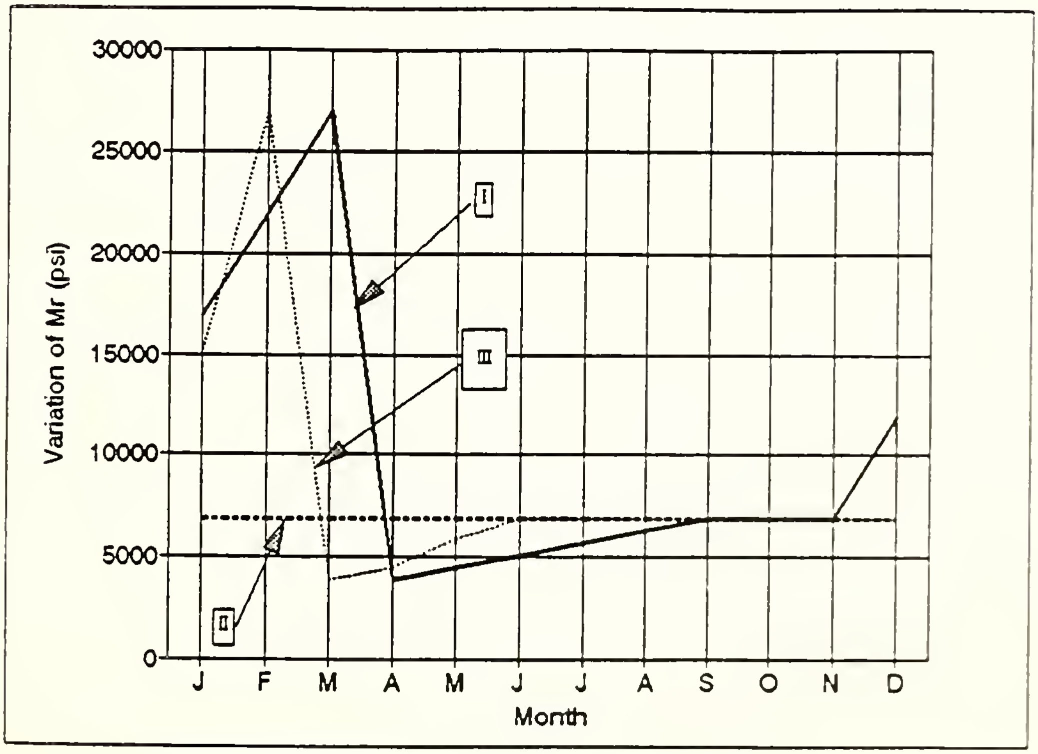

Fig. 10.12 Seasonal Variation of Resilient Modulus for the Example (Report Section 10.10.1)

<u>11) An example:</u> <u>Let us assume</u> a site whose subgrade soil is as that at the South Bend site of this project, an A-4/A-6 soil. Let us assume that an unconfined compression test was performed (item (3) above) on a specimen prepared as per item (2) of this procedure - and let us assume the stress causing 1.0% strain is 20.0 psi from the test results.

According to item (4) above, the as-compacted resilient modulus is:

$$M_{RN} = -1599.66 + 833.83(20.0) - 6.9683(20.0)^2$$

$$M_{RN} = 12290 \text{ psi}$$

Let us assume the estimate is made that water content will increase to create 90% degree of saturation, from an as-compacted at-optimum w, i.e. Δw = 1.0% from Table 10.2.

From the South Bend site diagram (Fig. 10.1) of item (6) above, ΔM_R = 5400 psi for the Δw = 1.0%.

Then, M_{RN} = 12,290 - 5400 = normal resilient modulus

M_{RN} = 6890 psi

The $S_{u1.0\%}$ that is associated with M_R = 6890 psi is back calculated from eqn. 4.8. Thus,

$$6890 = -1599.66 + 833.83\ (S_{u1.0\%}) - 69683\ (S_{u1.0\%})^2$$

$$S_{u1.0\%} = 11.24 \text{ psi}$$

The magnitude of $S_{u1.0\%}$ associated with the normal condition M_{RN}, is inserted into eqn. 5.3, to determine the thawed condition modulus, M_{RT}

$$M_{RT} = 2453.48 + 130.24(11.24)$$

$$M_{RT} = 3920 \text{ psi}$$

From Table 10.2, the frozen condition modulus, M_{RF} = 27,000 psi.

In this example, the fully frozen condition is expected at the beginning of March, thaw is expected to be complete at the beginning of April, the normal condition is expected from the beginning of September to the beginning of November, at which time freezing starts. This set of judgments is shown as Curve I on Fig. 10.12.

In order to determine the sensitivity of the design M_R (as per AASHTO Design Guide) to judgments about frozen, thawed, and normal conditions of subgrade, two additional sets of judgment examples were created. These are shown as Curves II and III on Figure 10.12.

The assembly of month-by-month moduli to create the design M_R is shown on Table A of this report. The monthly magnitudes of M_R are taken from the appropriate curves of Fig. 10.12, assuming a linear variation between the dates selected for the various subgrade conditions.

The data of Table A suggests that the design M_R may not be very sensitive to varying judgments about subgrade conditions.

The example presented was made using relations that are associated with an in-service confining pressure, σ_3, of 3 psi, and an applied loading deviator stress, σ_D, of 6 psi. The report provides a procedure to create the relations (used in the example) that correspond to other magnitudes of σ_3 and σ_D.

The example reported was made for a new-construction situation. If the situation is of a reconstruction, i.e., using a subgrade that

TABLE A. Calculation of Design Modulus
(refer also to Fig. 10.12)

Curve I: Freezing begins Nov., thawing begins Mar., thawing ends Apr., normal equilibrium establish Sept.

Curve II: No freezing/thawing; normal equilibrium the full year.

Curve III: Freezing begins Dec., thawing begins Feb., thawing ends Mar., normal equilibrium established Jun.

	M_R			μ_f		
Month	I	II	III	I	II	III
Jan.	16950	6890	15000	0.018	0.147	0.024
Feb.	21970		27000	0.010	0.147	0.006
Mar.	27000		3920	0.006	0.147	0.550
Apr.	3920		4500	0.550	0.147	0.395
May	4500		5900	0.395	0.147	0.211
June	5100		6890	0.295	0.147	0.147
July	5700			0.228	0.147	0.147
Aug.	6300			0.181	0.147	0.147
Sept.	6890			0.147	0.147	0.147
Oct.	6890			0.147	0.147	0.147
Nov.	6890			0.147	0.147	0.147
Dec.	11920			0.041	0.147	0.147
			Σ =	2.165	1.764	2.215
			$\bar{\mu}_f$ =	0.180	0.147	0.185
			M_R =	6300	6890	6239

$$\mu_f = 1.18 \times 10^8 M_R^{-2.32}$$

$$\bar{\mu}_f = \Sigma \frac{\mu_f}{12}$$

$$\text{design } M_R = \sqrt[2.32]{\frac{1.18x10^8}{\bar{\mu}_f}}$$

has been in-service, then the following changes are made to the described procedure.

1) The subgrade is sampled by pushing a 3-inch diameter Shelby tube to create the specimen for unconfined compression testing.

2) Using $S_{u1.0\%}$ obtained from the unconfined compression test, enter equation 4.8 to determine M_R. Because the subgrade has been in-service, its water content should be at the "normal" condition; the calculated M_R, then, is M_{RN}, as in the example.

3) The remainder of the procedure is as before, in the example.

Granular dense sand was also studied in this project. The resilient modulus was found to be independent of water content, and dependent on dry density and the stresses confining the specimen. The following relation may be used to predict the modulus:

$$M_R = (-20163 + 232.886\ RC)\ \theta^{0.595}$$

where M_R = resilient modulus, psi

RC = relative compaction = ratio of the as-compacted dry density to that obtained from 5-layer compaction by 5-minute vibratory compaction per layer on a shake table operating at 50 Hz.

The report contains a procedure by which the compaction specification can be developed that will assure the presence in the subgrade of a limiting desired specific resilient modulus. This procedure requires some agreement on what should be the limiting allowable deflection of a pavement surface, an agreement not now available.

COVER DESIGN BY ALDO GIORGINI